Generating High Quality Meshes in Gap Regions using Geometrical Information from the Medial Object

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1. Introduction

One of the major issues affecting advancing layer hybrid mesh generation for CFD applications is the relatively poor quality of the mesh between nearby components. This article describes recent work in which the medial object [1] has been exploited to provide geometrical and topological information in a novel approach to hybrid mesh generation for complex configurations. The idea behind the new technique is to generate a semi-structured local mesh in a region between nearby components of a model guided by the medial object. The SOLAR [2] mesh generator (jointly developed by BAE SYSTEMS, Airbus and ARA) is then used to produce a conformal volume mesh for the flow domain which incorporates the local mesh.

The advancing-layer method of mesh generation used in the SOLAR mesh generator to mesh the near-field is capable of producing high quality meshes for viscous flow solutions. However, the technique has the disadvantage, compared to structured meshing, in that it operates with only limited knowledge of the domain topology. The method builds a volume mesh from a surface mesh of the boundary of the flow domain by growing layers away from the boundary surface mesh, without regard for other regions of the boundary. In the absence of any knowledge of nearby boundary components, separate regions of the mesh may grow into each other. For example, this occurs in high-lift geometries where the layer mesh growing from the leading edge of a wing can intersect that growing from the trailing edge of a slat. This is avoided in SOLAR by using local pull back of the layer mesh which restricts how far the mesh can grow. This may lead to a deterioration of mesh quality, and robustness issues resulting from the need to interface an anisotropic near-field mesh with a tetrahedral far-field mesh which is isotropic.

On the other hand, structured meshing algorithms, such as transfinite interpolation, are based on a full knowledge of the boundaries of the domain, and therefore have the potential to be able to provide a much better mesh quality in narrow regions between components. The meshing technique described in this note exploits the advantages of both approaches by extracting information about the domain topology from the medial object.

2. The Medial Object

The medial object of a region in two dimensions is defined as the set of centre points of all maximal inscribed circles in the region [1]. These are circles contained within the region which are not strictly contained within any other circle inside the region. Topologically, the medial object is a collection of curves within the region which may intersect each other. Figure 1 shows the medial object for a rectangular region as dark blue curves, together with two maximal circles with centres lying on the medial object. The distance of a point on the medial object to the boundary is called the medial radius of the point. Similarly, the medial object of a closed region in three dimensions is the set of centre points of all maximal spheres inside the volume. The medial object is a collection of surfaces, which may join each other along branch curves.

A very good approximation to the medial object in three dimensions can be generated from a Delaunay tetrahedral mesh as follows (see [3], [4] and [5]). Firstly, a discrete set of points is chosen to approximate the boundary surface of the region. Then a Delaunay tetrahedral mesh is generated from these points. The vertices of each tetrahedron will belong to the chosen set of boundary points, and there are will be no vertices in the interior of the region. In the medial object implementation developed for this work, the approximation points are the nodes of a SOLAR surface mesh for which the spacing has been defined to resolve local details of the model. All tetrahedra outside the region are discarded. The circumsphere of a tetrahedron inside the region will normally approximate a maximal sphere in the region, but there may also be poor quality cells in the mesh (e.g. sliver tetrahedra) which do not correspond to maximal spheres. These cells lead to noise in the medial object and must be filtered out. The circumcentre of a remaining tetrahedron will approximate a point on the medial object, and its circumradius will approximate the medial radius at that point. The medial object can be approximated by a surface mesh defined by the set of edges between circumcentres of neighbouring tetrahedra. A face in the surface mesh will correspond to the set of tetrahedra sharing a common edge in the mesh. Tetrahedra can be classified by their geometrical or topological relationship with the boundary surface and this classification can be used to determine the topology of the medial object.

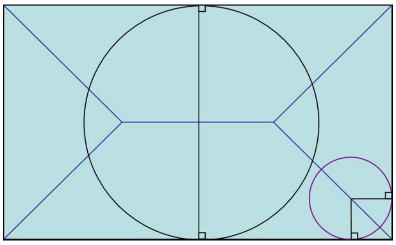

Fig. 1. The medial object for a rectangular region in the plane (shown in dark blue) together with two maximal circles. The lines from the centre of a maximal circle to the nearest points on the boundary of the region are normal to the boundary.

3. Local Meshing Using the Medial Object

The local meshing capability makes use of normal directions on the boundary surface mesh of the region and normal distances from the surface mesh to the medial object (see Fig. 2). The input to the local meshing algorithm is a connected region of the surface mesh on a ‘source’ component of the model together with a descriptor for the ‘target’ component of the surface mesh on the opposite side of the medial surface. Candidate regions for local meshing can be detected automatically from the medial object by searching for points of the medial object where the medial radius, and hence the distance between components is small. The faces of the surface mesh of the source region are swept out to the medial object along the normal directions at the face nodes, and then projected onto the target surface mesh. The local swept mesh is sliced into layers using layer heights consistent with advancing-layer mesh generation in SOLAR. A buffer layer of pyramids and tetrahedra is created from the outer layer of cells around the central region of the local mesh so that its boundary has triangular faces. The width of the central buffer region is configurable. The buffer layer is needed to interface with the tetrahedral SOLAR far-field mesh so that the local mesh can be embedded in a conformal volume mesh.

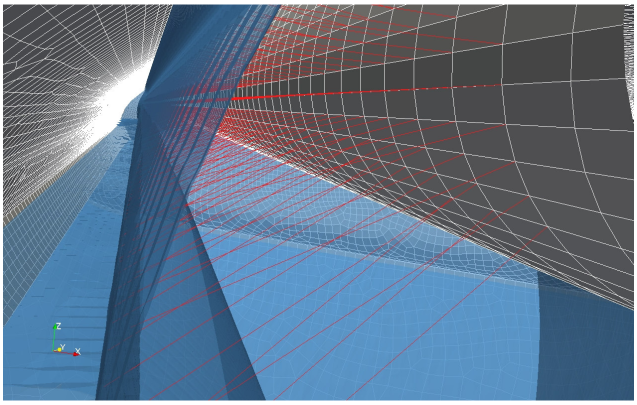

Fig. 2. Medial object (in blue) between leading edge of the wing and the slat in the NASA Trapwing model together with some surface normal vectors (in red).

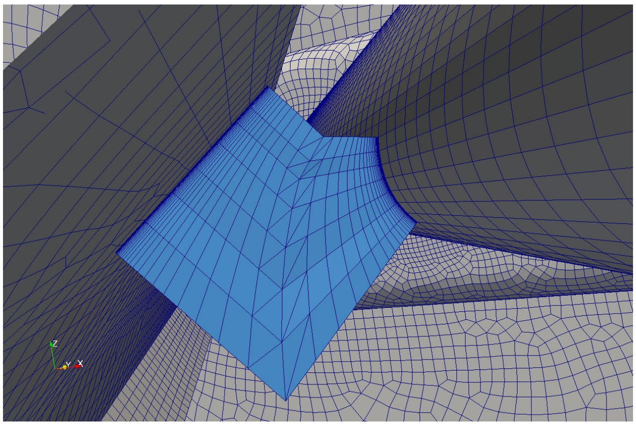

Fig. 3. A local mesh between the leading edge of the wing and the slat in the NASA Trapwing model (in blue). Note the triangular faces of the buffer region around the middle.

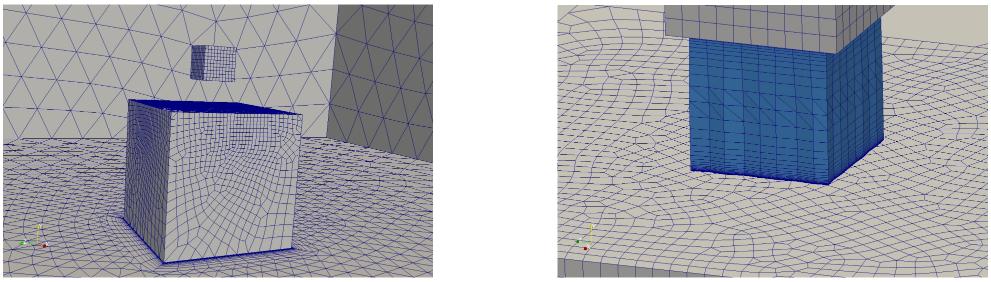

Fig. 4. Left: Box and Box model; right: local mesh for the Box and Box model shown in blue.

Figure 2 shows the medial object for the NASA Trapwing model between the leading edge of the wing and the slat and Figure 3 shows a local mesh in the same gap region. Figure 4 shows the Box and Box model consisting of a small box suspended above a large box and a local mesh in the gap region between boxes. Notice that the local mesh in the NASA Trapwing case does not grow directly across the gap, but instead follows the direction of surface normals out from the surface to the medial object. An annular region of the surface mesh around the projected mesh is identified and re-meshed in order to create a conformal interface. To obtain the annular region, the faces on the target surface mesh intersecting the boundary of the projected surface mesh are identified. This set of faces is expanded by adding successive layers of surrounding faces until a reasonably shaped annular region is obtained. The inner and outer boundary curves of this region are then identified and the surface in between is re-meshed (see Fig. 5 and Fig. 6).

The quality of the local mesh produced by this technique will be dependent on the curvature and relative orientation of the source and target surface regions. In some cases the projected surface mesh may be heavily distorted, and the local mesh may be of poor quality. But, for a relatively flat source and target region, the quality of the local mesh should be very good.

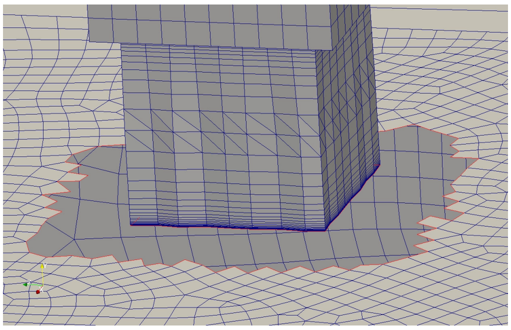

Fig. 5. Annular region of surface mesh in the Box and Box model target region near the projected surface mesh identified and removed before re-meshing. The boundary curves are shown in red.

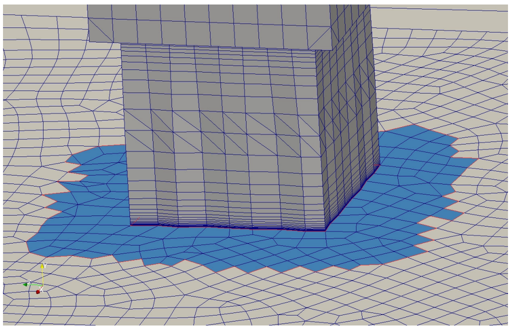

Fig. 6. Region of surface mesh in the Box and Box model target region after re-meshing in blue.

4. Generating a Complete Mesh

The usual SOLAR volume mesh for use with the Tau flow solver [6] is a hybrid mesh consisting of a hex-dominant advancing layer mesh in the near-field, and a tetrahedral mesh in the far-field. There is a buffer mesh of pyramids and tetrahedra between the near-field and far-field meshes used to provide a conformal interface between the two parts of the mesh. In a gap region, the SOLAR advancing layer mesh growing away from the surfaces either side of the gap will pull-back to avoid collision (see Fig. 8). Using the local meshing technique, a complete SOLAR volume mesh is generated incorporating the local mesh in which the layers of the SOLAR advancing-layer mesh 'snap to' the boundary nodes of the local mesh to ensure that the mesh is conformal. The gap region is now spanned by a semi-structured, advancing layer mesh of a higher quality than the normal SOLAR mesh in the same region. This would be particularly useful in high-lift configurations, such as the region between a wing and a flap. The tetrahedral SOLAR far-field mesh will also be conformal with the central buffer region of the local mesh because the triangular faces of the local buffer boundary are included in the definition of the region of SOLAR far-field meshing.

5. Conclusion

A complete hybrid volume mesh has been generated that incorporates a semi-structured advancing layer mesh in a gap region of a model. The local mesh in the gap has been generated using geometrical and topological information obtained from the medial object for the model. The technique shows great potential for generating meshes in gap regions between nearby components, of significantly higher quality than is possible using traditional advancing layer approaches.

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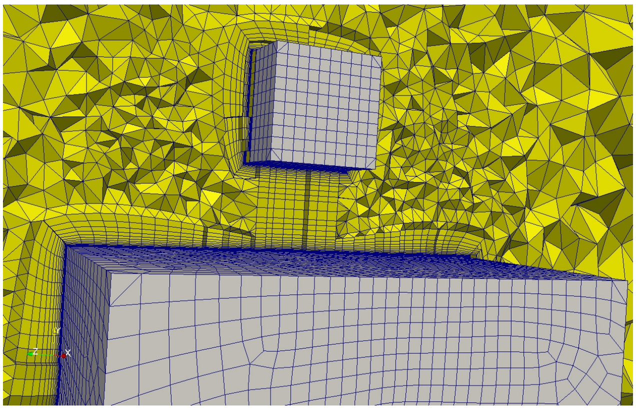

Fig. 7. Cross-section of local mesh in the Box and Box model embedded in SOLAR volume mesh.

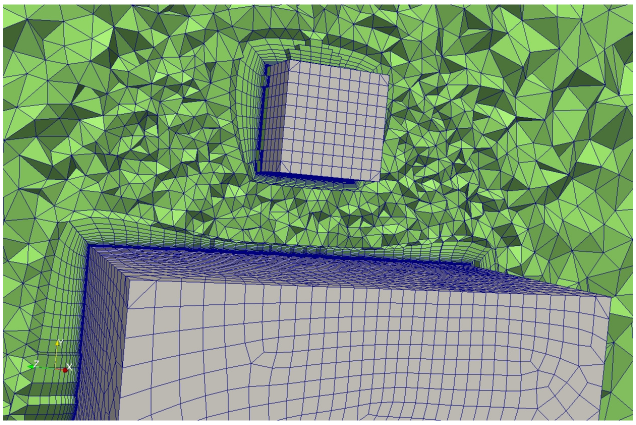

Fig. 8. Cross-section of normal SOLAR volume mesh for the Box and Box model showing pull-back of the near-field mesh in the gap region.

References

1. H A Blum. Transformation for Extracting New Descriptors of Shape. In Models for the Perception of Speech and Visual Form, 1967.
2. M Leatham, S Stokes, J A Shaw, J Cooper, J Appa, T A Blayloc. Automatic Mesh Generation for Rapid-Response Navier-Stokes Calculations, AIAA Paper 2000-2247, 2000.
3. X Yu, J A Goldak, L Dong. Constructing 3-D Discrete Medial Axis. In Proceedings of the First ACM Symposium on Solid Modeling Foundations and CAD/CAM applications, 1991.
4. J M Reddy, G Turkiyyah. Computation of 3D Skeletons Using a Generalized Delaunay Triangulation Technique. Computer-Aided Design, 27 (9), 1995.
5. D Sheehy. Medial surface computation using a domain Delaunay triangulation. In Proceedings of the third ACM symposium on Solid modeling and applications, 1995.
6. T Gerhold, O Friedrich, J Evans, M Galle. Calculation of Complex Three-Dimensional Configurations Employing the DLR-Tau-Code, *AIAA Paper* 97-0167, 1997.